CALCULATION OF THE THERMAL FLUX ABSORBED BY COLLOIDAL CAPILLARY-POROUS SOLIDS BEING DRIED BY THERMAL RADIATION

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The results of an experimental investigation into the drying of potato starch by thermal radiation are presented. Using the generalized Rb (Rebinder) variable, the kinetic characteristics of the thermal flux absorbed by the starch are established.

In engineering calculations relating to heat treatment it is essential to know the thermal flux (heat flow) $q_{ab}(\tau)$ absorbed by the material.

If the heat is conveyed by radiation, then in order to calculate $q_{ab}(\tau)$ we must find the reduced emission coefficient c_{red} of the system, the surface temperature of the material T_s, and the temperature of the radiators T_r; in order to calculate c_{red} we need to know the emissivity of the solids undergoing heat transfer, allowing for their mutual disposition. The analytical calculation of c_{red} is very difficult and can only be achieved for very simple cases [1].

One of the most effective means of calculating $q_{ab}(\tau)$ is that proposed by A. V. Lykov [2] based on the use of the generalized Rb variable.

The greatest problem here lies in calculating the volumetric mean temperature after assuming a parabolic temperature distribution over the thickness of the material.

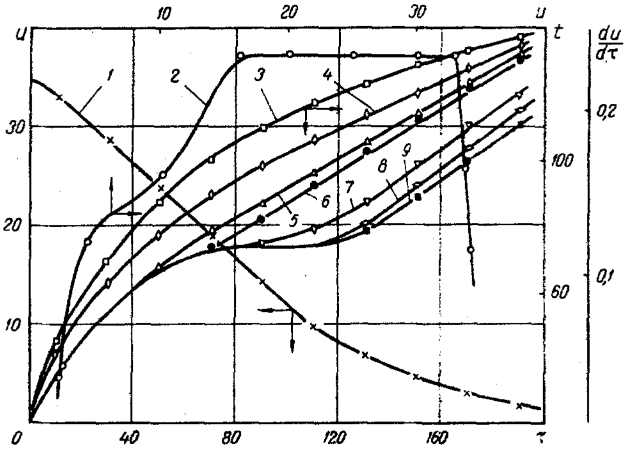

Fig. 1. Kinetic characteristics of the drying of starch by thermal radiation at E = 8000 W/m²: 1) drying curve; 2) drying-rate curve; 3), 4), 5), 6), 7), 8), 9) temperature of the starch at distances from the surface of 1, 3, 5, 8.5, 11, 13.5, and 15 mm; u, %; τ, min; t, °C; du/dτ, %/min.

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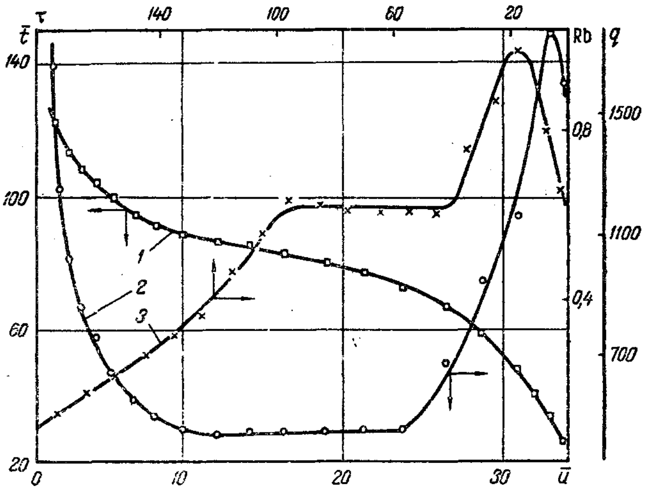

Fig. 2. 1) Volumetric-mean temperature of the starch $\bar{t} = f(\bar{u})$; 2) Rebinder criterion $\mathrm{Rb} = f(\bar{u})$; 3) thermal flux absorbed by the starch $q_{ab}(\tau)$; q in W/m^2.

In order to determine the volumetric mean temperature as a function of the integrated mean humidity $\bar{t} = f(\bar{u})$ in the course of drying by this method, we must know the local temperatures of the material.

We carried out some experiments on the drying of native potato starch, as a typical colloidal capillary-porous solid, with unilateral heating by means of a set of ZS-3 mirror drying lamps and natural convection of the air. The spectral composition of the radiation from "bright" infrared ZS-3 radiators, as indicated earlier [3], is best matched to the optical properties of the starch. The intensity of irradiation in our experiments varied from 6000 to 9500 W/m^2, a range giving excellent technological indices of the dried starch. The thickness of the layer of loose starch was 16 mm, the bulk density $\rho_0 = 650$ kg/m^3. The layer-by-layer temperature of the material was measured with copper-Constantan thermocouples placed at various depths and recorded on the paper of an ÉPP-09M1 automatic recording potentiometer. The weight loss of the material was measured with a photobalance [4] and recorded automatically by the ÉPP-09M1 potentiometer.

Figure 1 represents the kinetic drying curves. We see that the drying of potato starch with infrared radiation involves periods of constant and falling rates of drying. The development of the temperature fields takes place in a very intensive manner.

Even at the onset of drying, the excess of the temperatures at depths of 1 and 3 mm (curves 3 and 4 in Fig. 1) over the temperatures of the lower layers indicates that the infrared radiation penetrates to a certain finite depth, and this leads to the more intensive heating of these layers. The detachment of temperature curves 5, 6, and 7 (Fig. 1) must clearly be associated with the deepening of the zone of evaporation.

Using the temperature curves and the drying curve (Fig. 1) together with the relationships given in [2], we calculated $\bar{t} = f(\bar{u})$ (Fig. 2, curve 1). In the period of constant drying rate we noted a certain rise in $\bar{t}$, which agreed with the results of the earlier experiments [2] involving intensive modes of heat inflow.

The sharp rise in $\bar{t}$ beginning from $\bar{u} = 10\%$ is due to the fact that in this period the greater part of the heat is used in heating the material up in preparation for the detachment of the adsorbed moisture, [5].

The Rb (Rebinder) number was calculated from the equation [2]

$$\mathrm{Rb} = \left(1 + \frac{c_{\text{в}}}{c_0}\bar{u}\right)\frac{c_0 b}{r}, \tag{1}$$

where $c_0 = f(\bar{t})$, $c_B = f(\bar{t})$, and $r = f(\bar{t}, \bar{u})$. In order to obtain the values of $c_0 = f(\bar{t})$ we carried out a special investigation. The values of $r = f(\bar{t}, \bar{u})$ were taken from [4] and those of b and $\bar{u}$ directly from the drying experiments.

The resultant $\mathrm{Rb} = f(\bar{u})$ relation is shown in Fig. 2 (curve 2). At the beginning and end of the drying process the values of Rb were large compared with those in the period of constant drying rate. This indicates that the amount of heat used in heating up the material exceeds the amount of heat required for the evaporation of the moisture. The large values of Rb at the onset of drying may be explained by the fact that in these experiments the starch drying process started from $\bar{u} = 35\%$. For this moisture content the moisture in starch is mainly in the combined form, and strong heating is required to remove it. At the end of the drying process there is a monolayer of moisture attached to the starch, very strongly indeed from the energy point of view, and this also leads to an increase in the Rb number. Knowing the $\mathrm{Rb} = f(\bar{u})$ relationship and being in possession of the $d\bar{u}/d\tau = f(\bar{u})$ curve, we may calculate the thermal flux absorbed by the starch on drying by thermal radiation from the equation [2].

$$q_{\mathrm{ab}}(\tau) = \rho_0 R_v r \frac{d\bar{u}}{d\tau} (1 + \mathrm{Rb}). \tag{2}$$

The resultant $q_{\mathrm{ab}}(\tau)$ curve is presented in Fig. 2 (curve 3). We see from the figure that the maximum value of $q_{\mathrm{ab}}(\tau)$ and its subsequent fall belong to the period of the initial heating of the material, characterized by a complex distribution of moisture content with respect to thickness [6]. In the period of constant drying rate, this quantity remains approximately constant. In the period of falling drying rate, the absorbed thermal flux diminishes. The general tendency toward a fall in $q_{\mathrm{ab}}(\tau)$ during the drying process may be explained by the increase in the reflection coefficient with diminishing moisture content [7].

Analogous $q_{\mathrm{ab}}(\tau)$ relationships occur in the drying of potato starch by thermal radiation with other radiation parameters.

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